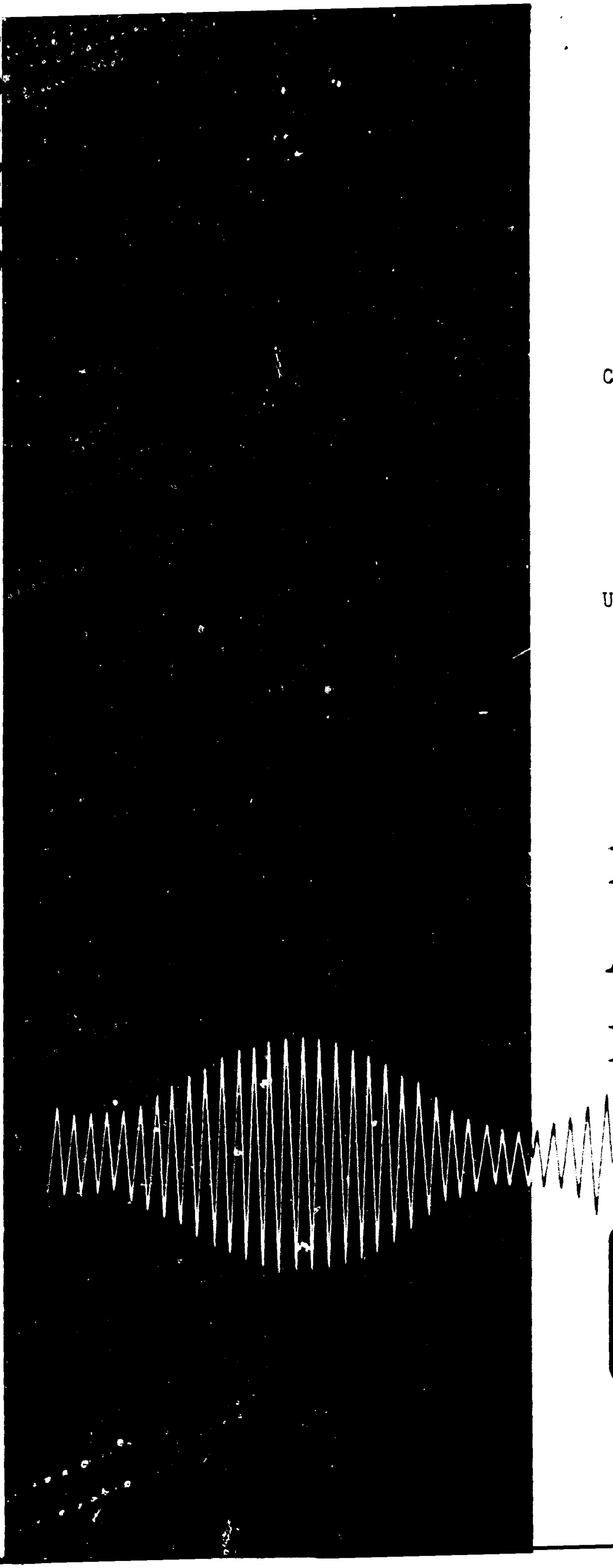

MINIATURIZED X-BAND

STRIPLINE DUPLEXER

Report No. 3

Contract No. DA-36-039-AMC-03230(E)

Task No. 1G6-22001-A-055-04

THIRD QUARTERLY PROGRESS REPORT

1 January 1964 to 31 March 1964

U. S. ARMY ELECTRONICS LABORATORIES
FORT MONMOUTH, NEW JERSEY

MICROWAVE
ASSOCIATES,
INC.

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Technical Requirement SCL-5929 14 January 1963

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FORT MONMOUTH, NEW JERSEY

The object of this program is to develop a miniaturized stripline duplexer for use in a lightweight radar system.

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Project Manager
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MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS

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SECTION I

PURPOSE

The objective of this program is the development, construction and evaluation of a miniaturized stripline duplexer for use in a lightweight radar system. The duplexer shall be capable of operation in the X-band frequency range between 9.0 and 10.0 Gc. The duplexer to be developed and constructed shall be designed to operate with a single microwave generator. The microwave generator shall supply both the transmitter and the local oscillator signals. During the transmit cycle, the duplexer shall provide a low loss transmission path between the transmitter input port and the antenna port, and at the same time the duplexer shall isolate the mixer from the high power transmitter pulse. During the receive part of the cycle, the signal from the antenna shall be transmitted to the mixer circuit with low loss and at the same time the local oscillator signal incident at the transmitter input port is transmitted to the mixer with low loss.

SECTION II

ABSTRACT

A prototype design of a 3 port stripline circulator was presented. Low loss performance was achieved over a 400 mc band centered at 9,450 mc.

The design of a quadrature stripline 3 db hybrid was discussed. Isolation in excess of 18 db was obtained over a 500 mc band, however, the power split was excessive at the high end of the band. An insertion loss of 0.2 db was obtained on this preliminary unit.

A number of diode limiter configurations are presented. By varying the electrical spacing between the two diodes and by adjusting the diode stub impedance, insertion loss values ranging from 0.8 to 1.4 db can be obtained on low level, with 33 to 45 db isolation obtained under forward bias.

CONFERENCES

On 30 January 1964, a meeting was held at Microwave Associates, Inc., Burlington, Massachusetts, attended by Messrs. R. True of USAEL and R. Brunton and J. Christian of Microwave Associates, Inc. The program was reviewed in general with specific design problems associated with the stripline circuitry and limiter discussed in detail.

On 16 March 1964, a meeting was held at USAEL, Evans Area, Fort Monmouth, New Jersey, attended by Messrs. I. Rheingold, J. Carter and W. Wright of USAEL and L. Gould, P. Martin, and N. Brown of Microwave Associates, Inc. The principal purpose of this meeting was to review the accomplishments and to accelerate the effort. It was agreed that Microwave Associates would continue the study of the individual components and to plan on their use in two different circuit configurations - one to be used with a dual mode transmitter and the other with a conventional type transmitter. Tentative plans were made for a future meeting at USAEL to discuss packaging problems.

On 19 March 1964, a meeting was held at Microwave Associates, Inc., Burlington, Massachusetts, attended by Messrs. R. True of USAEL and R. Brunton, J. Christian, S. Segal and N. Brown of Microwave Associates, Inc. The purpose of the meeting was the specific discussion and review of the circulator, video detector, hybrid and the limiter work.

SECTION IV

FACTUAL DATA

I INTRODUCTION

1.1 Program Objectives

This is the third quarterly report on a program to develop a Miniaturized Stripline X-Band Duplexer. The duplexer shall be capable of operation in the X-band frequency range between 9.0 and 10.0 Gc. The duplexer to be developed and constructed shall be designed to operate with a single microwave generator. The microwave generator shall supply both the transmitter and the local oscillator signals. During the transmit cycle, the duplexer shall provide a low loss transmission path between the transmitter input port and the antenna port and, at the same time, the duplexer shall isolate the mixer from the high power transmitter pulse. During the receive part of the cycle, the signal from the antenna shall be transmitted to the mixer circuit with low loss and, at the same time, the local oscillator is transmitted to the receiver port with low loss.

1.2 Detailed Electrical Requirements

(a)	Frequency Range	
	(1) Minimum	9.2 to 9.[illegible] Gc
	(2) Maximum	9.[illegible] to 10.[illegible] Gc
(b)	Pulse Recurrence Rate (prr)	[illegible] kc Max.
(c)	Duty Cycle (Du)	[illegible] Max.
(d)	Peak Power (po)	[illegible] W. Min.

(e)	Average Power (Po)	1 W. Min.
(f)	Pulse Width	
	(1) Minimum	0.2 μsec.
	(2) Maximum	1.0 μsec.
(g)	Recovery Time	0.5 μsec.
(h)	High Power Insertion Loss	
	Port 1 to Port 2	1.0 db Max.
(i)	High Power Spike Leakage Energy	
	(1) Port 1 to Port 3	0.2 ergs Max.
	(2) Port 1 to Port 4	0.2 ergs Max.
(j)	High Power Flat Leakage Power	
	(1) Port 1 to Port 3	20 mw Max.
	(2) Port 1 to Port 4	20 mw Max.
(k)	High Power Isolation	
	Port 2 to Port 1	12 db Min.
(l)	Low Level Insertion Loss	
	(1) Port 2 to Mixer	1.0 db Max.
	(2) Port 1 to Mixer	0.5 db Max.
(m)	High Power VSWR, Port 1	1.4 Max.
(n)	Life*	500 Hours Min.

*Based on a mixer sensitivity degradation of 2 db Max.

2.0 SOLID-STATE LIMITER MODULE

2.1 Technical Objective

The objective of this sub-effort is to design a semiconductor switched limiter module for incorporation into the first duplexer.

The switched limiter module will consist of two stages of semiconductor limiting and a high burnout crystal diode detector. The first limiter stage will be a PIN diode and will be followed by a varactor diode second stage. The crystal detector will be decoupled from the main line and will be located before both limiter stages. The crystal detector output pulse will be applied to the PIN and varactor diodes to drive them into forward bias during the transmitting mode, thereby causing the limiting action. This type of operation is called a switched limiter.

2.2 Accomplishments During the Third Quarterly Period

A test fixture has been designed to incorporate shunt stubs with limiter diodes mounted in these stubs. A loop coupling has been designed to couple the high burnout diode sufficiently to the main transmission line to provide the necessary bias for high power limiting. Measurements of low level DC bias operation and preliminary high power results have been obtained for the switched limiter operation. The test fixture used in these tests has been described in previous reports, however, many modifications have been incorporated. The present fixture with waveguide-to-stripline transitions uses a .350 inch ground plane width, 50 ohm stripline, and 20 ohm diode shunt stubs. A loop coupling has been provided for the high burnout bias crystal. Provisions have been made in

the test fixture for experimental measurement of several electrical spacings between the PIN and varactor diode elements. Provisions have also been made to change impedance of the limiter diode shunt stubs. Through changing the impedance of these stubs, the effective Q of these stubs or elements can be changed. Experimental results have been obtained for electrical spacings of 100° between elements and also for 240° spacing between elements.

2.3 Electrical Measurements

The waveguide-to-stripline test fixture used for measurements during this quarter is shown in Figure (1). The fixture utilizes a 50 ohm stripline and a .350 inch wide ground plane width. This has been designed to reduce the size of the overall package and also reduce any possible higher modes caused by the discontinuities from the shunt stub which cuts into the ground plane. Measurements of PIN and varactor diodes in this fixture have shown improvement in both insertion loss and isolation as compared to measurements in previous fixtures. Typical data for a PIN diode and a varactor diode are shown in Figures (2) and (3) respectively; these measurements were taken at low level using DC bias for the isolation condition. These data also show the effect of changing the shunt stub center conductor diameter, thereby changing the impedance of the stub and lowering the Q of the element. The lower Q provides lower insertion loss and lower isolation by varying the impedance of the stub. Isolation may be traded off for insertion loss and vice versa. Selection of the PIN or varactor diode is therefore made on the basis of minimum insertion

loss and maximum isolation obtained in a standard fixture. A diode providing high isolation and reasonably low insertion loss can be used in these stubs and isolation can be traded off for reasonable insertion loss.

Insertion loss figures of less than .8 db from 9.2 to 9.7 Gc has been measured for both PIN and varactor diodes in the stripline test fixture. Measurements of isolation for both PIN and varactor diodes in the same stripline test fixture have resulted in maximum isolation on the order of 25 to 28 db at 9.4 Gc decreasing to 18 db minimum on the edges of the band. Measurements have been taken of a two stage limiter utilizing a PIN and a varactor diode spaced 240° electrical degrees apart, this data is shown in Figure (4). The minimum insertion loss in this case was 1.2 db in the center of the band, 1.8 db at 9.2 Gc and 1.55 db at 9.7 Gc. The isolation was greater than 45 db from 9.3 to 9.5 Gc, the isolation at 9.2 Gc was 37 db and at 9.7 Gc was 36 db. A second measurement of a dual diode limiter was taken using 100° electrical spacing between elements. These test results are shown in Figure (5). The insertion loss in this measurement was less than .9 db from 9.1 Gc to 10.3 Gc. The bandwidth of isolation, however, was considerably less in this case, resulting in 32 db of isolation at the band edges 9.2 to 9.7 Gc and 37.6 db isolation at 9.45 Gc. Figures (4) and (5) illustrate the trade off of isolation for lower insertion loss. Measurements of the two diode stripline limiter test fixture for the 100° spacing were repeated and are shown in Figures (6) and (7). In Figure (6), the stub impedance is 28 ohms. This data shows less than 1 db insertion loss and greater than

32 db isolation over the 9.2 to 9.7 Gc range. Figure (7) uses a 20 ohm stub impedance. This data shows an insertion loss of less than .8 db over the band and isolation greater than 28 db over the 9.2 to 9.7 Gc range. Figures (6) and (7) clearly show the trade off of isolation for insertion loss through the variation of the stub impedance. The results shown in Figures (6) and (7) approach those required of a limiter to meet the requirements of the miniature stripline duplexer program, therefore, high power tests were taken using these configurations.

Before measuring the high power performance of a dual diode limiter combination, a coupling loop and a high bur ut bias diode were fabricated and measured in a stripline fixture. The coupling was adjusted so that maximum bias was obtained at 500 watts peak input power. The data for this loop and bias crystal combination is shown in Table I. A 10 ohm load was placed on the crystal, and the bias current measured through the 10 ohm resistor was recorded for peak input powers of 1 watt to 500 watts. The maximum peak bias current was 94 ma. After the measurement and evaluation of the coupling loop and bias diode circuit, a PIN diode was assembled into the stripline fixture and connected to the bias diode. The low level measurements using DC bias of the PIN diode was .65 db insertion loss and 26.2 db isolation.

The combination PIN and high burnout diode was then tested under high power. The input power was raised from 1 watt peak to 500 watts peak. The total average leakage was measured over this range, the diode provided 20 db of isolation at 500 watts peak input. The leakage wave form indicated a spike energy of 22.5 ergs and a flat leakage power of 1.1 watts.

No instability was noted at 500 watts and the PIN diode appeared to be operating very satisfactorily.

A varactor diode was assembled in the stripline test fixture and measured at low level providing .6 db insertion loss and 23.8 db isolation at 9.45 Gc under DC bias conditions. The varactor was then connected to the high burnout bias diode and high power was applied from 1 watt to 10 watts peak input power. At 10 watts peak input power, the diode provided 21.2 db isolation and showed a slight instability in performance indicating the maximum power capability of the diode at 10 watts.

The test data for the PIN and varactor diodes under high power are shown in Figures (8) and (9) respectively. The next measurement was performed using both the PIN and the varactor diode with the bias diode providing bias to both diodes. Table II shows the data taken during this measurement. The peak input power was varied from 1 watt to 500 watts. Total average leakage is shown and the bias provided for the PIN and varactor diodes is also shown in this table. This data was taken at 9.45 Gc with 500 watts peak power. The leakage characteristics indicate a flat leakage of 50 milliwatts, a spike energy of .18 erg. This data is very close to meeting the requirements of the contract.

3.0 3 DB QUADRATURE HYBRID

The initial design work conducted during the second quarter on the 3 db quadrature hybrid has been completed. A prototype model of this hybrid has been constructed and evaluated. The test results on this

prototype are shown in graphic form in Figure (8). The following conclusions have been reached relative to this test data:

(a) Isolation -- the values achieved will be adequate to fulfill the needs of the system requirement.

(b) Insertion Loss -- .2 db appears to be the maximum to be anticipated from this hybrid including connectors and transitions. This value may tend to diminish toward .1 db when mounted in the duplexer system.

(c) Output Unbalance -- the output unbalance at the higher end of the band has been caused by two distinct parameters. The impedance of the coupling junction must be lowered slightly to center the power split. The resonant lengths within the hybrid must be shortened slightly to raise the operating frequency. The bandwidth of the power split can be increased by removing some slightly asymmetrical condition within the coupling structure.

Work will continue into the fourth quarter to optimize those parameters affecting the bandwidth and power balance of the quadrature hybrid. It is felt with reasonable certainty that the adjustment of the coupling junction impedance and shortening of the resonant line lengths, along with a rearrangement of the phase centers of the junction branch arms will solve the coupling and bandwidth problems associated with the present 3 db Quadrature hybrid.

4.0 FERRITE CIRCULATOR MODULE

4.1 Final Technical Objectives

The final objectives in the development of the ferrite module are:

a) Mechanically suitable for mounting in the finished duplexer assembly.

b) Electrically compatible with the requirements of the duplexer assembly.

The electrical requirements for the ferrite circulator are listed as follows:

a)	Frequency Range:	9.0 - 10.0 Gc
b)	VSWR:	1.3 Maximum
c)	Isolation:	15 db Minimum
d)	Insertion Loss:	.5 db Maximum
e)	Average Power:	1 Watt Maximum
f)	Peak Power:	500 Watts Minimum

4.2 Accomplishments During Third Quarterly Period

A three port stripline circulator was constructed and tested during this period. Various sizes of ferrite and matching disks were investigated. The ferrite material was purchased from Microwave Chemical Laboratory, their Type MCL 1110M, with the following characteristics:

Saturation Magnetization	=	1200 gauss
Ferrimagnetic Linewidth	=	80 oersteds
Dielectric Loss Tangent	=	.001
Curie Temperature	=	250°C.
Dielectric Constant	=	15.2

The best resulting performance of the above material was found for a garnet diameter of .500" by .062" thick with a .350" diameter by .002" thick matching disk. The data as shown in Figure (9) is encouraging as it was found possible to obtain less than 0.5 db insertion loss over essentially a 400 mc band.

SECTION V

CONCLUSIONS

1. The stripline circulator will have to be improved. A wider bandwidth with improved isolation is necessary.
2. The power split of the 3 db quadrature hybrid should be improved.
3. The design of a miniature direction coupler in the form of a coupling loop has been completed.
4. The diode limiter should be improved in terms of its insertion loss-isolation trade off.
5. Power handling of the limiter is satisfactory.
6. Spike leakage energy of the limiter meets the specification, the flat leakage does not.

SECTION VI

PROGRAM FOR NEXT INTERVAL

1. Investigate and improve ferrite material.
2. Purchase commercially available stripline circulator.
3. Improve 3 db hybrid performance.
4. Minimize stripline losses.
5. A single channel dual diode switched limiter will be fabricated in a stripline module. The input and output coupling will be compatible with coupling provided by the hybrid and the circulator.
6. PIN and varactor diodes applicable to the stripline two stage limiter will be evaluated in order to characterize diodes for this program.
7. High burnout crystal detectors will be investigated in order to determine the most satisfactory type to be utilized in this program.
8. Complete packaging of circulator, coupler, hybrid, and limiter will be investigated.

IDENTIFICATION OF PERSONNEL

This section contains a list of key technical personnel assigned to the contract and taking part in the work covered by this report. The approximate man hours of work performed on the contract by each of the people listed are given.

PERSONNEL	MAN HOURS
Norman J. Brown (Project Manager)	14
Robert H. Brunton, III (Project Engineer)	12
James W. Christian (Project Engineer)	58
Robert Tenenholtz (Project Engineer)	20

TABLE I

PIN and Bias Diode Performance

1. Low Level Characteristics.

Frequency	VSWR	Insertion Loss*	Isolation**
9.45 Gc/s	1.27	0.65 db	27.5 db

2. High Power Characteristics 500 Watt Peak, Du = .001, 1.0 microsecond pulse.

Frequency	Spike (Power)	Spike (Energy)	Flat (Power)
9.45 Gc/s	75 watts peak	22.5 ergs	1.1 watts peak

3. Bias Diode Current vs. Peak Power Input.

Frequency	Load
9.45 Gc/s	10 Ω in series with PIN diode.

Peak Power (Watts)	Bias Current (ma)
1	1
2	4
5	13
10	20
20	36
50	52
100	68
200	80
300	86
400	92
500	94

*Insertion Loss was measured with zero bias.

**Isolation was achieved with forward DC bias.

TABLE II

Varactor and Bias Diode Performance

1. Low Level Characteristics

Frequency	VSWR	Insertion Loss*	Isolation**
9.45 Gc/s	1.26	0.6 db	23.8 db

2. High Power Characteristics 10 watts peak, Du = .001, 1.0 microsecond pulse.

Peak Power Input (Watts)	Average Leakage Power (Micro-watts)	Bias Current to Varactor and Series 22Ω Resistor (Milli-amps.)
1	19	3
2	23	5
3	26	6
4	33	9
5	40	13
6	46	15
7	55	18
8	58	21
9	65	24
10	75	27

*Insertion Loss is measured with zero bias.

**Isolation was achieved with forward DC bias.

TABLE III

PIN, Varactor and Bias Diode Performance

1. Low Level Characteristics.

Frequency	VSWR	Insertion Loss*	Isolation**
9.45 Gc/s	1.13	1.1 db	37.8 db

2. High Power Characteristics 500 watts Peak, Du = .001, 1.0 microsecond pulse.

Frequency	Spike (Power)	Spike (Energy)	Flat (Power)
9.45 Gc/s	740 mw	.18 ergs	50 mw

3. Bias Diode Current vs. Peak Power Input

Frequency	Load
9.45 Gc/s	PIN Diode 10 Ω Series Resistor Varactor Diode 22 Ω Series Resistor

Peak Power Input (Watts)	Bias Current PIN Diode	Bias Current Varactor Diode
1	0	0
2	0	0
5	0	2
10	6	2
20	10	3
50	17	6
100	24	9
200	31	15
300	34	18
400	37	20
500	39	22

*Insertion Loss was measured with zero bias.

**Isolation was achieved with forward DC bias.

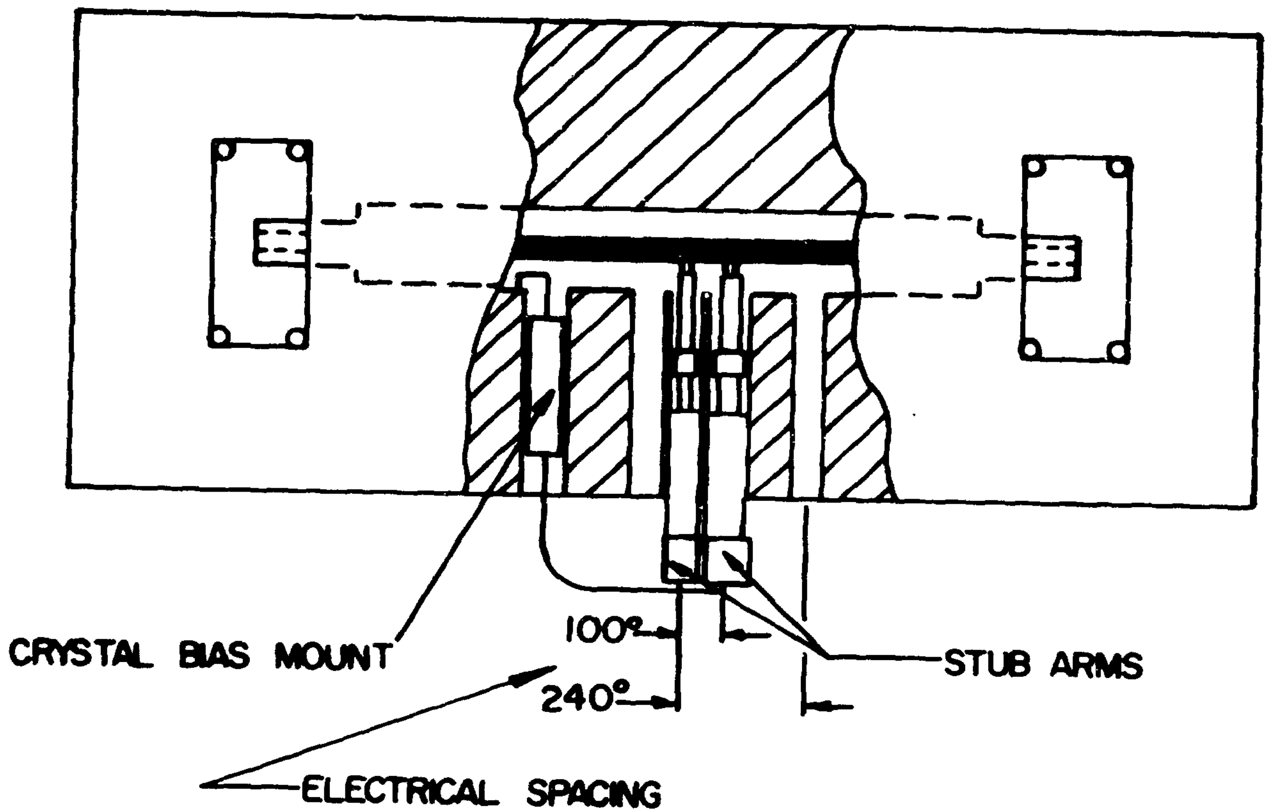


FIGURE 1

WAVEGUIDE TO STRIPLINE TEST FIXTURE

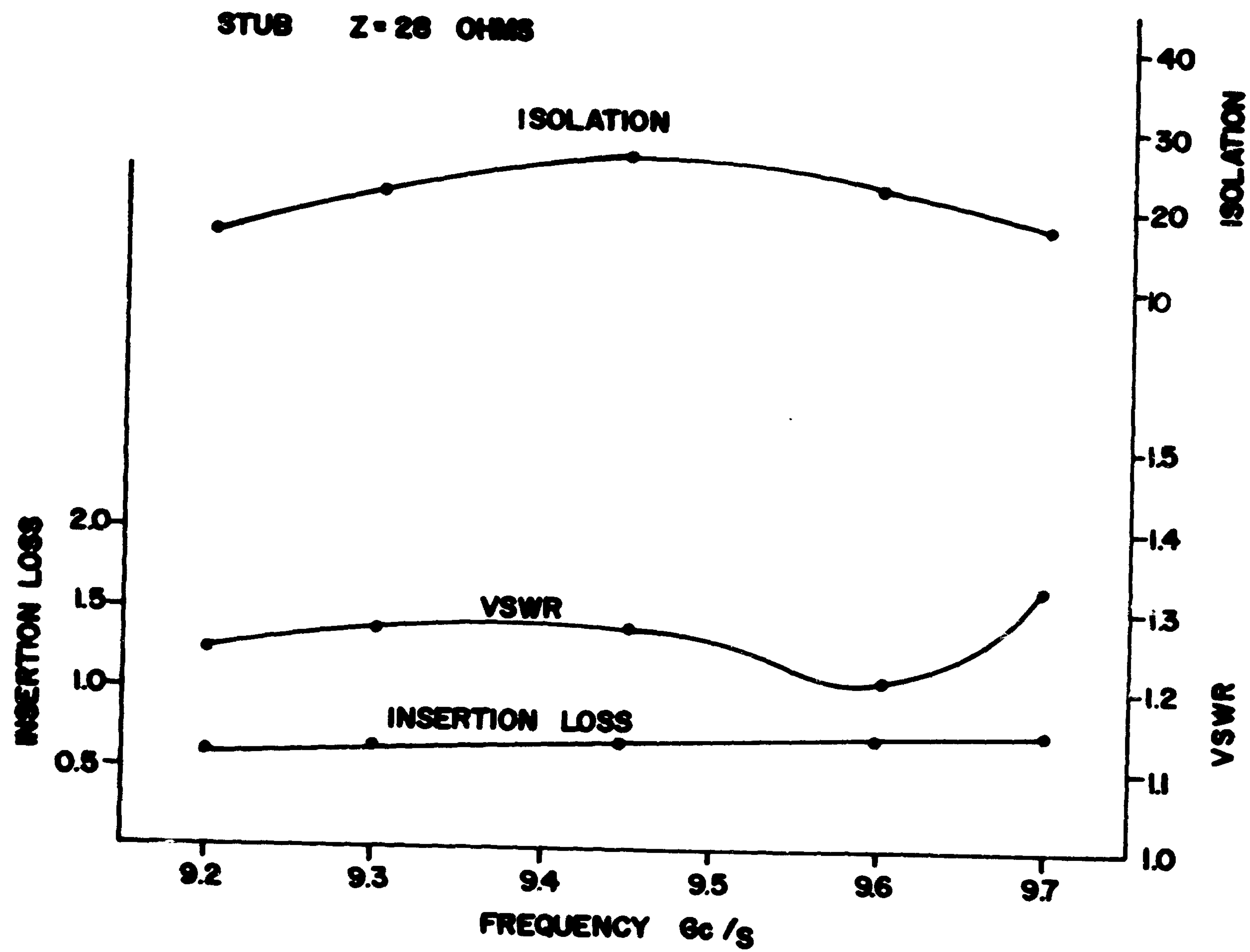


FIGURE 2

LOW LEVEL CHARACTERISTICS PIN DIODE

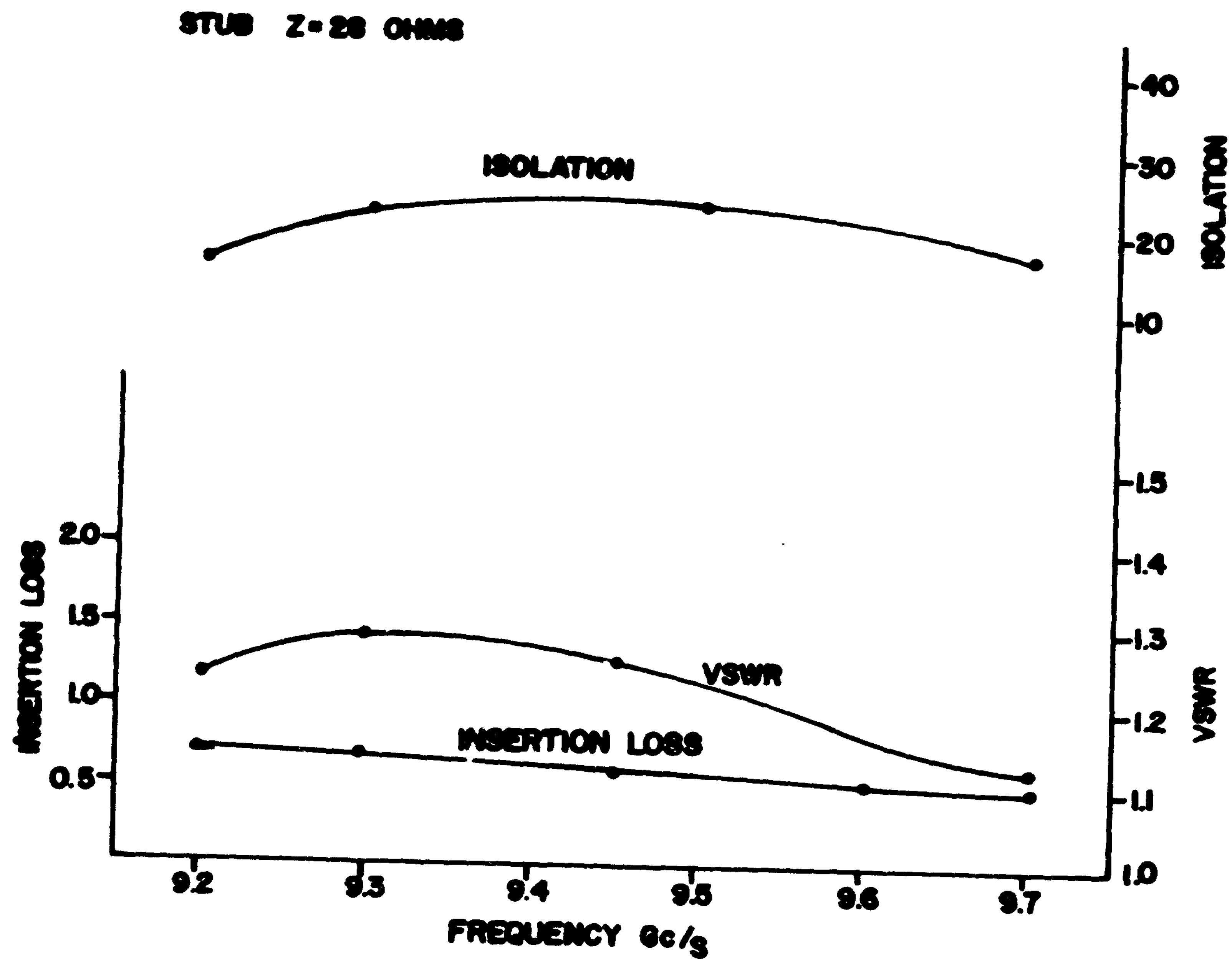


FIGURE 3

LOW LEVEL CHARACTERISTICS VARACTOR DIODE

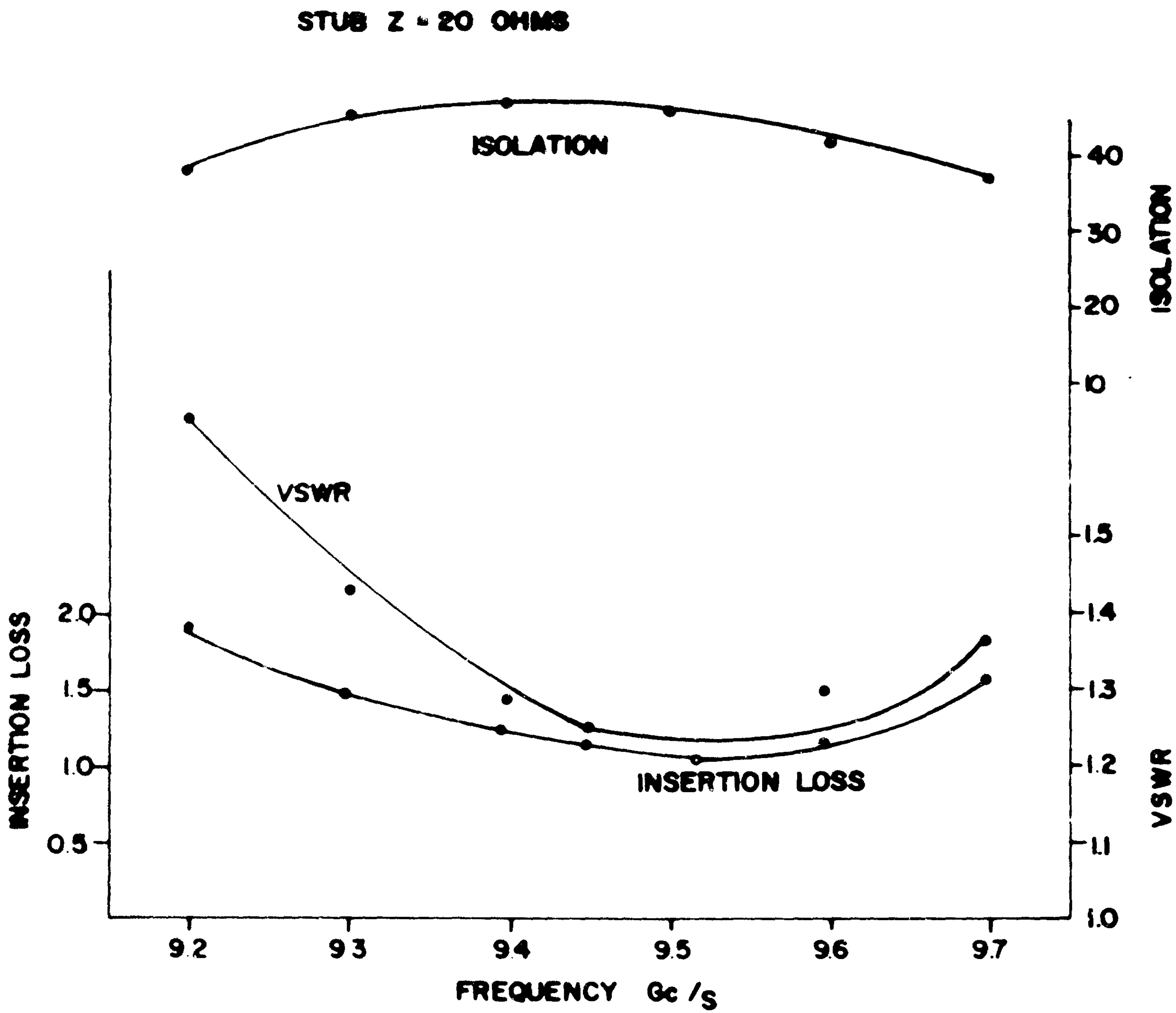


FIGURE 4
LOW LEVEL CHARACTERISTICS PIN AND VARACTOR SPACED 240° BETWEEN CONDUCTOR

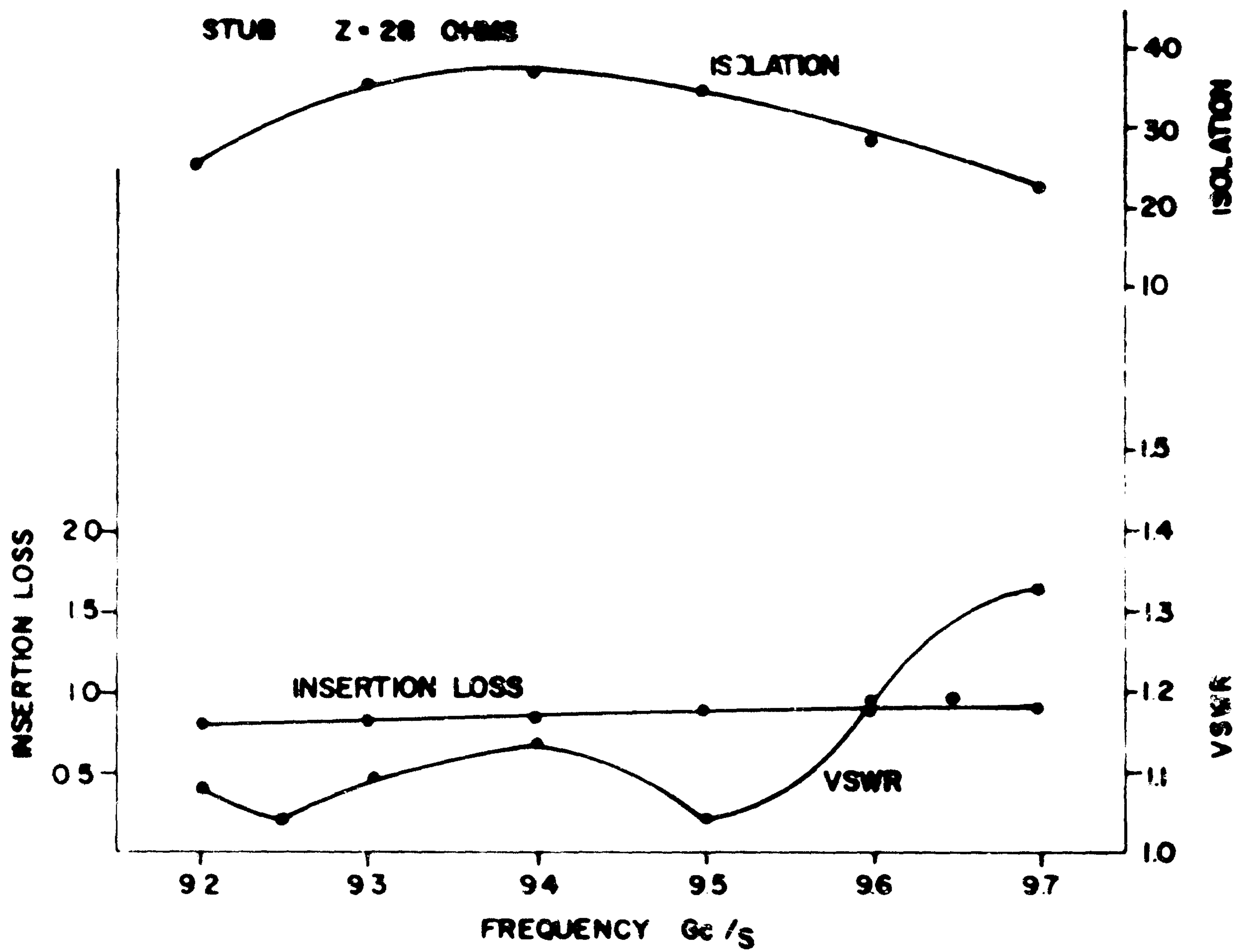
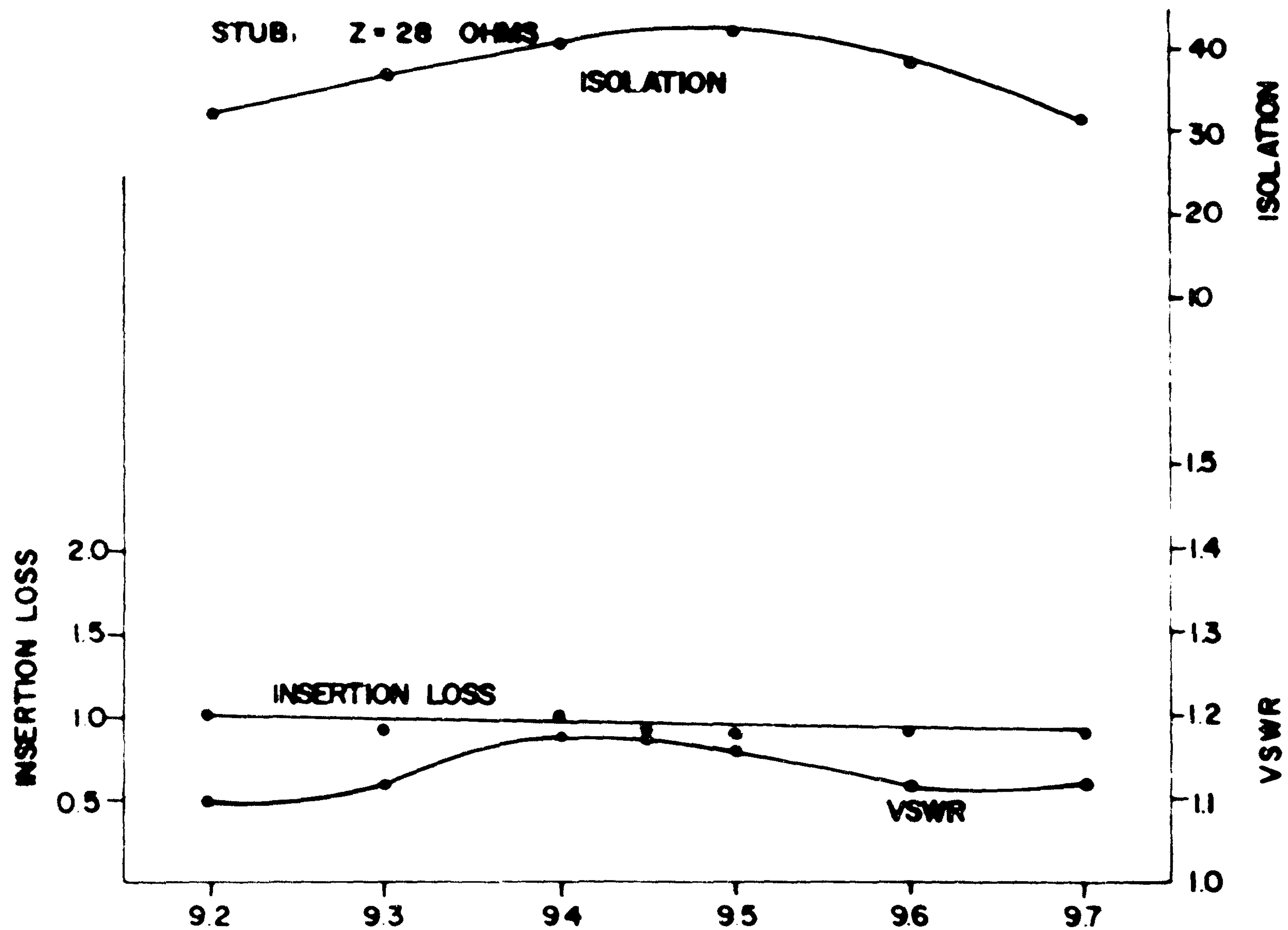


FIGURE 5

LOW LEVEL CHARACTERISTICS PIN AND VARACTOR
SPACED 100° BETWEEN CONDUCTOR



FREQUENCY Gc/s

FIGURE 6

LOW LEVEL CHARACTERISTICS PIN AND VARACTOR
SPACED 100° BETWEEN CONDUCTOR

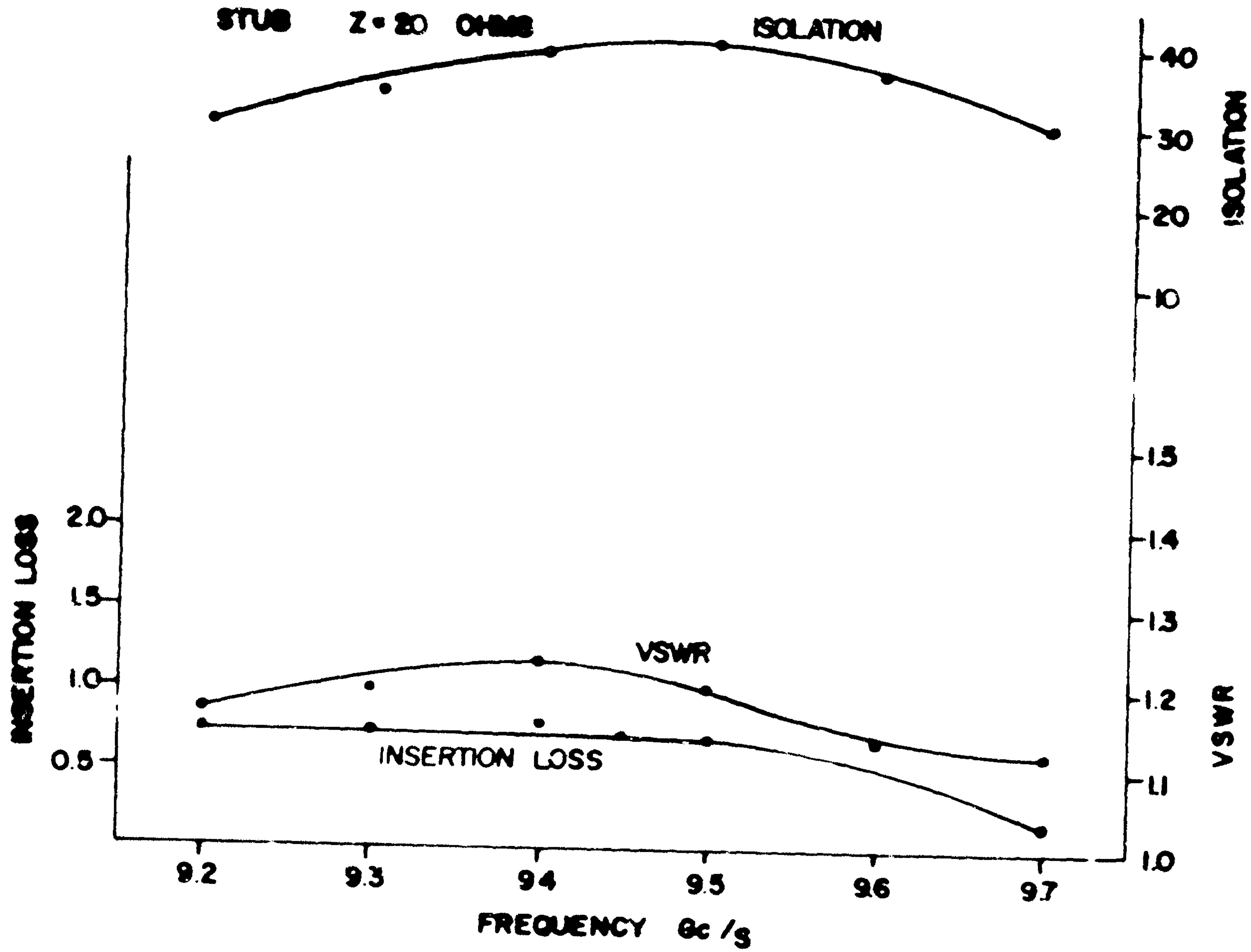
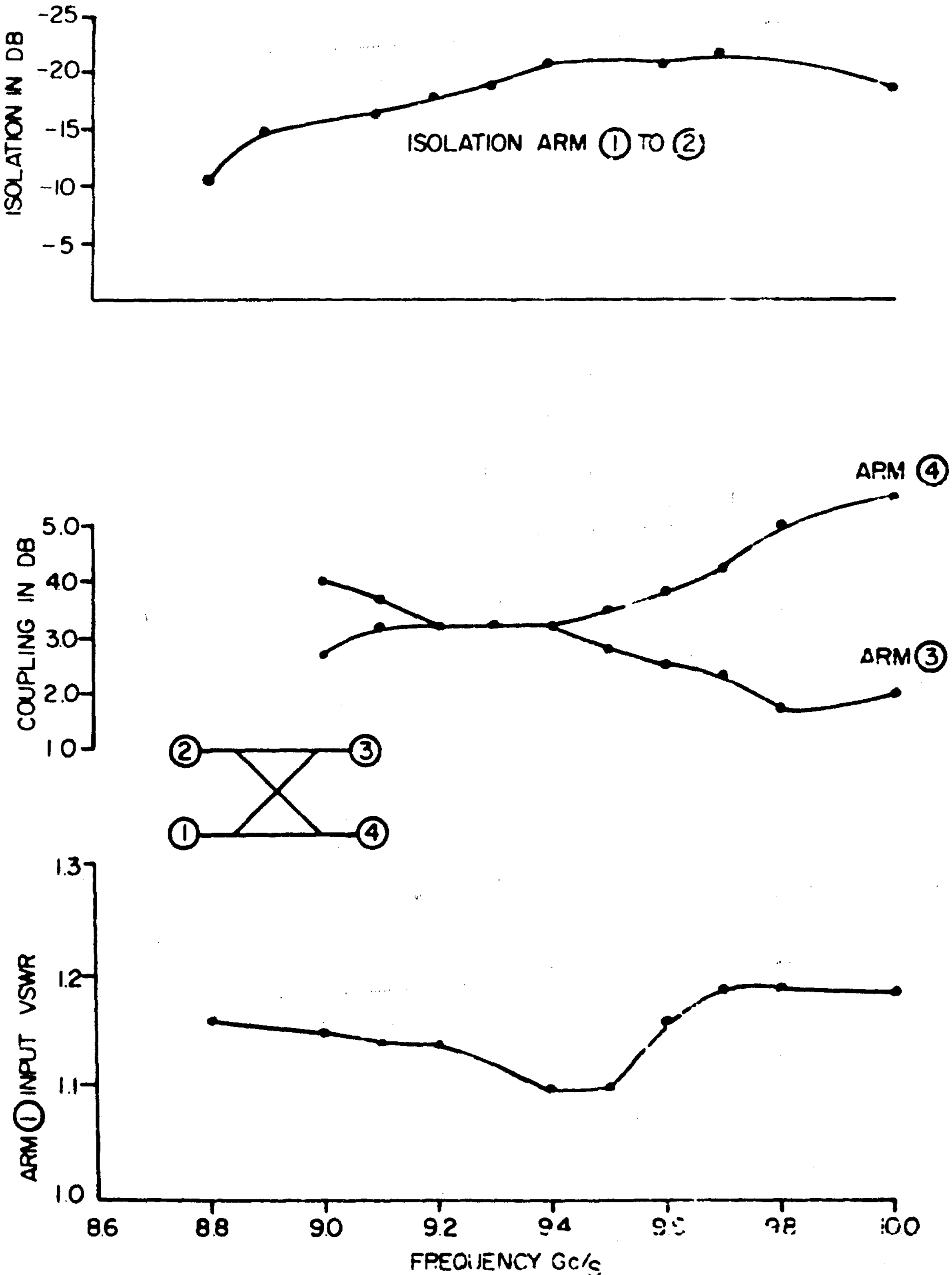


FIGURE 7

LOW LEVEL CHARACTERISTICS PIN AND VARACTOR SPACED 100° BETWEEN CONDUCTORS



ISOLATION IN DB
-25
-20
-15
-10
-5
ISOLATION ARM (1) TO (2)
COUPLING IN DB
5.0
40
3.0
2.0
1.0
ARM (4)
ARM (3)
(2)
(3)
(1)
(4)
ARM (1) INPUT VSWR
1.3
1.2
1.1
1.0
8.6
8.8
9.0
9.2
9.4
10.0
FREQUENCY Gc/s

FIGURE 8

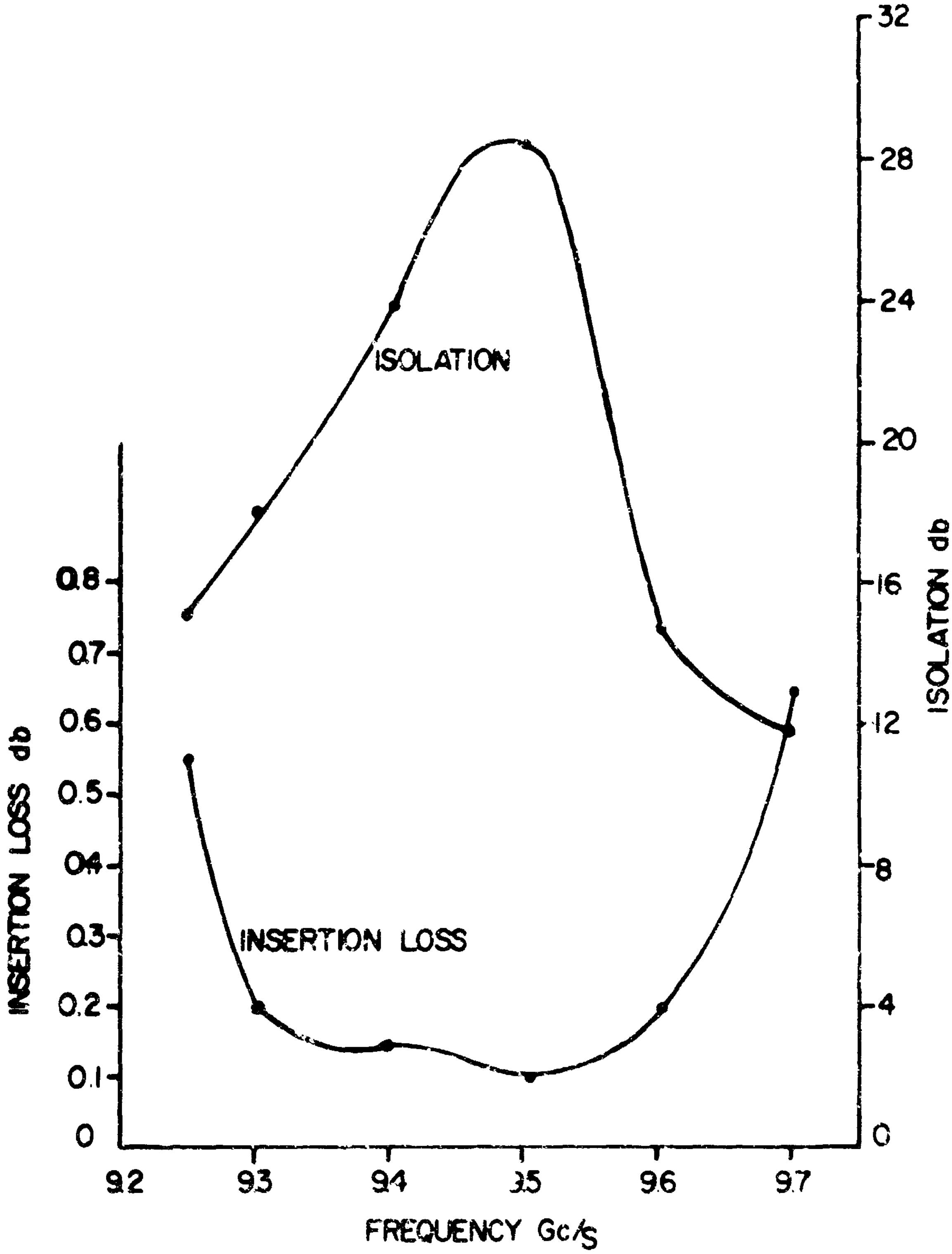


FIGURE 9

STRIPLINE CIRCULATOR
MCL 1110M GARNET
FERRITE: 500 DIA. x .062 THICK
MATCHING DISK: .350 x .002 THICK